LASER TECHNOLOGY. INC.

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MANAGEMENT BRANCH
AUG 18 AM 9:34

February 2, 1993

Mr. Jerome E. Dennis, Chief
Light Products Branch
HFZ-312
Center for Devices and Radiological Health
1390 Piccard Drive
Rockville, MD 20750

Dear Mr. Dennis,

I am writing in response to your letter dated September 23rd 1992, in which you mentioned the proposed changes to the Federal Performance Standard for Laser Products. The proposed changes would require surveying equipment to use a 10^4S measurement time period, as well as the repetitive pulse reduction factor. This would mandate a reduction of output power by a factor of 33.4 for LTI's laser products. Such a large reduction would render the technology useless. I feel quite strongly that the current specification provides a more than adequate safety margin for the type of lasers that LTI produces and have enclosed a brief analysis in support of this contention. The analysis compares the actual retinal energy density produced by LTI's laser products with laser damage threshold data, as well as estimating the instantaneous temperature rise for each pulse. (The laser damage threshold data was supplied by Dr. Ernst Sutter during a recent visit to the PTB in Braunschweig, Germany.)

The use of pulsed lasers for surveying is a fairly recent innovation that has great potential to improve speed and efficiency of data collection, for a wide range of applications. For example, the U.S. Forest Service recently conducted extensive field trials of the LTI Criterion 400 survey laser. They found that the instrument allowed timber cruising and traversing tasks to be completed 2 to 3 times faster than with conventional methods, with a much higher degree of accuracy. This is particularly important because the planned timber harvest has increased to nearly 6 Billion board feet ($1.8 Billion), at the same time as Forest Service operating budgets have been cut.

I agree that the standards must be set to ensure product safety. I also agree that bringing the U.S. standards closer to international standards makes a lot of sense. However, setting unnecessarily stringent standards not only makes it difficult for companies such as LTI to do business, but also will be to the detriment of the U.S. economy.

Sincerely,

J.C. Dunne

Jeremy Dunne
Vice President of Engineering

93N-004,

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ANALYSIS OF EYE SAFETY MARGINS FOR THE LTI 20-20 AND CRITERION SERIES LASER TRANSMITTERS

The following analysis derives the margin of safety for the LTI 20-20 and CRITERION series instruments under 3 conditions. First, viewing with the unaided eye. Second, viewing through a 50mm aperture telescope with the whole optical system diffraction limited. Third, viewing through a diffraction limited 50 mm telescope with the actual transmit lens assembly used in the LTI instruments.

1) Conditions and assumptions

a. Figure 1. shows the dependence of retinal lesion threshold on image size for several different wavelengths and exposure durations. The data for 15nS and 1064nM provides the best approximation to the output of the LTI lasers. The data for 15nS and 1064nM conforms to the following power law:

Retinal Radiant Exposure (RRE) = $260 * (\text{dia.})^{-0.903}$ J/cm*

Since the maximum allowable exposure is less for shorter wavelengths, the retinal radiant exposure value should be reduced by the ratio of the k, factors for 1064nM and 904nM:

$$\text{reduction} = 10^{((904-700)/515)} , 10^{((1064-700)/515)}$$
$$= 0.490$$

So the value used for retinal radiant exposure at the lesion threshold is:

RRE = $127 * (\text{dia.})^{-0.903}$ J/cm*

b. Since the retinal radiant exposure at the lesion threshold is inversely proportional to image diameter, the total retinal image area of the laser diode image is used to calculate safety margins. Considering the laser diode image as 3 separate stripes would give a larger safety margin.

c. There is some disagreement as to the smallest retinal image size for near infrared radiation with the eye fully dilated. The most conservative value appears to be approximately 10 microns (IEC825 amendment 1 1990-08, appendix B2.1), so this value is used in this analysis.

d. Since the retinal image of the laser diode is magnified in proportion to the power of the viewing telescope, the viewing telescope is the worst case condition where a 50mm beam is concentrated to a 7mm beam.

e. The retinal absorption of the infrared radiation produced by the LTI instruments is probably distributed among several layers in the retina. However, for a worst case temperature rise calculation, the absorption zone will be considered to be the same thickness as the minimum image size.

f. For calculation purposes, the effective focal length of the eye is assumed to be 20mm.

9" Table 1. shows the relevant specifications for the LTI 20-20 and CRITERION series laser transmitters (U.S. models) .

2) Viewing with the unaided eye

For viewing along the optical axis of the laser transmitter with the unaided eye, the transmitter lens is close to diffraction limited. So the image height on the retina is simply the source length of the emitting diode multiplied by the ratio of the eye's focal length to that of the transmitter lens:

retinal image height = 230uM * 20/87
= 52.9uM

If the minimum image size is 10uM, then the actual retinal image of the laser diode stripe would approximate to a rectangular stripe of dimensions 10um by 60uM. Since there are 3 stripes in the laser diode, the total image area is:

retinal image area = 3 * 10um * 60um
= $1800um^2$

a. Safety margin

The retinal image has the same total area as a circle of diameter 47.9uM. Putting this diameter into the formula for the retinal radiant exposure at the lesion threshold gives:

RRE = 127 * (47.9)-0.903
= 3.86 J/cm^2

so the total energy at the lesion threshold, for a retinal image of $1800uM^2$ is given by:

Pulse Energy = 3.86 * 1800 * 10^{-8}
= 69uJ

The maximum pulse energy through a 7mm aperture, measured at 20cms, for the LTI laser transmitter is 20nJ. So the exposure from the LTI lasers is 2.9 * 10^{-4} of the energy at the lesion threshold.

b. Temperature rise

If the absorption zone is assumed to be 10uM thick, then the irradiated volume is:

volume = $1800uM^2$ * 10UM
= $1.8 * 10^{-8}\ cm^3$

The specific heat capacity of water is 4.2 J/gin/K and the density is 1 gm/cm^3 so the temperature rise of the irradiated volume is:

temperature rise = (pulse energy) / ($1.8 * 10^{-8}$ * 1 * 4.2)
= (pulse energy) * $1.32 * 10^{7}$ K/J

Since the maximum energy through a 7mm aperture is 20nJ, the actual temperature rise is 0.26°C.

3) **Viewing through a 50mm-7mm telescope diffraction limited from source to retina.**

Figure 2. shows the complete optical system for viewing through the worst case telescope configuration. In order to make the optical system diffraction limited from the diode source to the observer's retina, the transmit lens has been replaced by a diffraction limited piano-aspheric element. The observer's eye is modelled by an aspheric element with an effective focal length of 2 0mm.

The retinal exposure described in this section is extremely unlikely to happen in practice because the actual LTI transmit lens has a significant amount of optical aberration. In fact, the only way that diffraction limited exposure could happen would be if someone were to design a telescope that specifically compensated for the aberrations in the transmit lens. Such a telescope would not be suitable for normal use.

Figure 3. shows the result of a random ray trace through the optical system at full aperture. The height of the image is in close agreement with the expected image height, based on the magnification of the telescope. The narrow width of the image shows that the optical system has negligible aberrations. Using the minimum retinal image size of 10uM, the total image area is:

retinal image area = 3 * 10um * 390um
= $11{,}700um^2$

a. Safety margin

The retinal image has the same total area as a circle of diameter 122uM. Putting this diameter into the formula for the retinal radiant exposure at the lesion threshold gives:

$$RRE = 127 * (122)^{-0.903}$$
$$= 1.66\ J/cm^2$$

so the total energy at the lesion threshold, for a retinal image of $11{,}700uM^2$ is given by:

$$\text{Pulse Energy} = 1.66 * 11{,}700 * 10^{-8}$$
$$= 194uJ$$

The maximum pulse energy through a 50mm aperture, for the LTI laser transmitter is 416nJ. So the exposure from the LTI lasers is $2.1 * 10^{-3}$ of the energy at the lesion threshold.

b. Temperature rise

If the absorption zone is assumed to be 10uM thick, then the irradiated volume is:

$$\text{volume} = 11{,}700uM^2 * 10uM$$
$$= 1.17 * 10^{-7}\ cm^3$$

The temperature rise of the irradiated volume is:

$$\text{temperature rise} = (\text{pulse energy}) / (1.17 * 10^{-7} * 1 * 4.2)$$
$$= (\text{pulse energy}) * 2.04 * 10^6\ K/J$$

Since the maximum energy through a 50mm aperture is 416nJ, the actual temperature rise is 0.85°C.

4) Viewing through a 50mm-7mm telescope with diffraction limited telescope and LTI laser transmit lens.

Figure 4. shows the same optical system as in figure 3. but with the actual LTI transmit lens instead of the diffraction limited lens. Both the telescope and the observer's eye remain diffraction limited.

Figure 5. shows the result of a random ray trace through the optical system at full aperture. (The horizontal scale is 8 times the horizontal scale of figure 3.) The focal plane is at the position of maximum image intensity. The effects of the optical aberration in the transmit lens assembly are clearly apparent, with a significant proportion of the energy contained in a diffuse halo.

Figure 6. shows the same view as figure 5., with the horizontal scale expanded 4 times. The central image area is approximately 350uM by 24uM. Also, by inspection, less than 30% of the energy lies in the central image area. The total retinal image area of concern is:

retinal image area $= 3 * 24um * 350um$
$= 25,200\ um^2$

a. Safety margin

The retinal image has the same total area as a circle of diameter 179uM. Putting this diameter into the formula for the retinal radiant exposure at the lesion threshold gives:

RRE $= 127 * (179)^{-0.903}$
$= 1.17\ J/cm^2$

So the total energy at the lesion threshold, for a retinal image of $25,200uM^2$ is given by:

Pulse Energy $= 1.17 * 25,200 * 10^{-8}$
$= 295uJ$

The maximum pulse energy concentrated in the central image area is 125nJ, so the exposure from the LTI laser is $4.2 * 10^{-4}$ of the energy at the lesion threshold.

b. Temperature rise

If the absorption zone is assumed to be 10uM thick, then the irradiated volume is:

volume $= 25,200uM^2 * 10uM$
$= 2.52 * 10^{-7}\ cm^3$

The temperature rise of the irradiated volume is:

temperature rise $=$ (pulse energy) / $(2.52 * 10^{-7} * 1 * 4.2)$
$=$ (pulse energy) $* 9.45 * 10^5\ K/J$

Since the maximum energy in the central image area is 125nJ, the actual temperature rise is 0.12°C. Note that this is less than half of the temperature that occurs when viewing with the unaided eye.

5) Conclusions

Under all normal viewing conditions, with or without magnification, the LTI laser transmitters have a huge margin of safety; approximately 1/2400 of the known damage threshold, or less. Also the maximum retinal temperature rise is only 1/4°C, or less. Even under the most unrealistic viewing conditions, the safety margin is still 1/460 of the known damage threshold and the maximum retinal temperature rise is less than 1°C.

These large safety margins would indicate that a reduction of output power by a factor of 33.4 is unnecessary. (As would be required by a measurement time of 10^4S, with a 50mm aperture and the $N^{-1/4}$ repetitive pulse reduction factor.)

The retinal temperature rise is too small to cause any damage. Also the thermal time constant for the very small irradiated zone is less than lmS. So at the PRF of the LTI lasers, there is no significant cumulative temperature rise. If there is no damage mechanism and no cumulative effects, then there is no need for a repetitive pulse reduction factor.

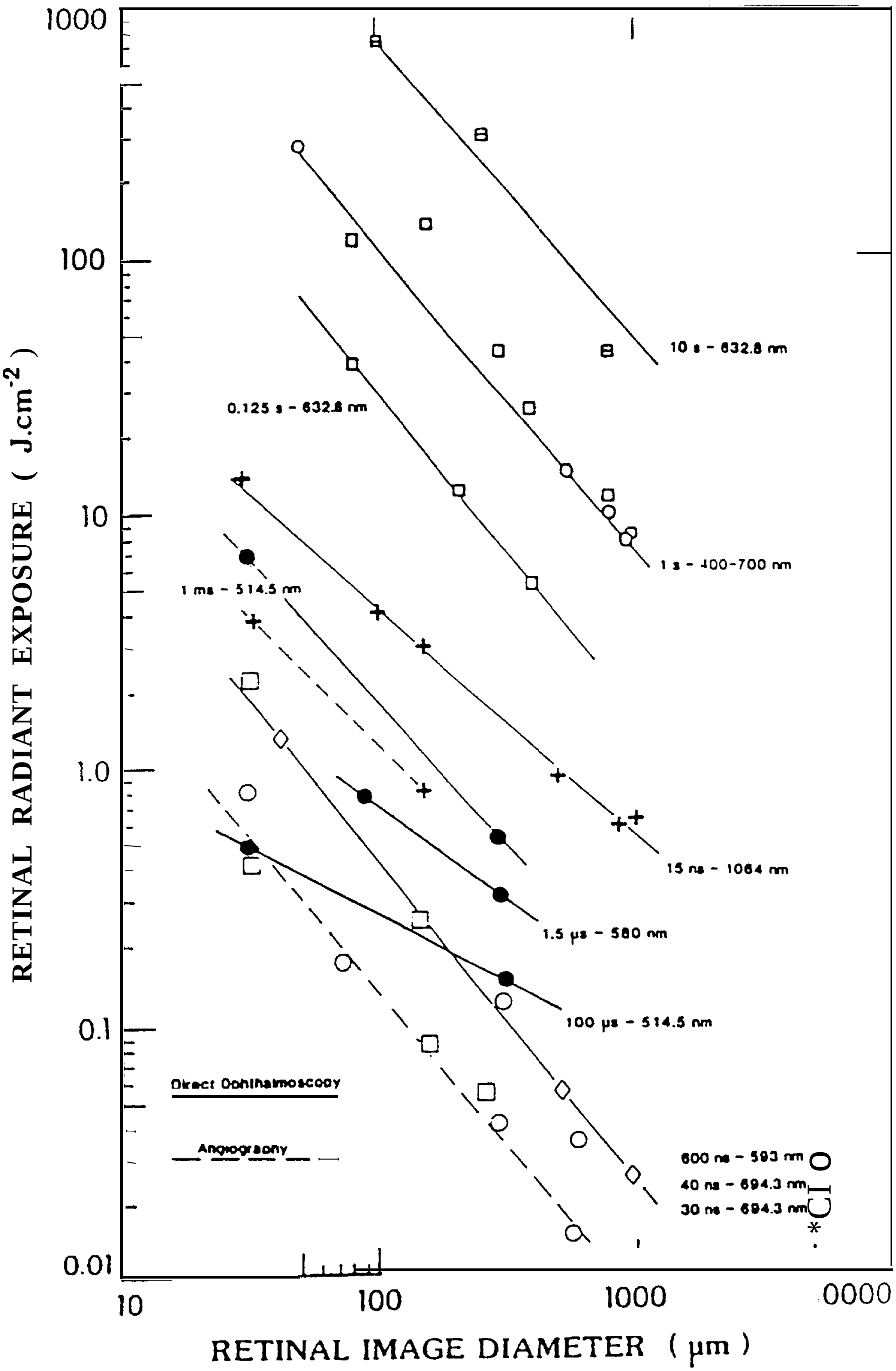
LTI 20-20 AND CRITERION SERIES LASER TRANSMITTERS

U.S. SPECIFICATIONS

Diode type	GaAs 3 layer stack
Stripe geometry	8 uM by 230 uM
Emission area, total	200 uM by 230 UM
Diode wavelength	904 nM
TX lens exit aperture	48.6 mm
TX lens focal length	87 mm
Exit beam divergence	3.5 mrad (full cone angle)
Pulse repetiton frequency	125 Hz
Average total TX power	52 UW (50 mm measuring aperture)
Single pulse energy	416 nJ
Pulse duration	12 nS
Peak pulse power	34.7 w
Max. average power, 7 mm	2.5 UW (at 20 cms from TX lens)
Single pulse energy, 7 mm	20 nJ (at 20 cms from TX lens)

Table 1.

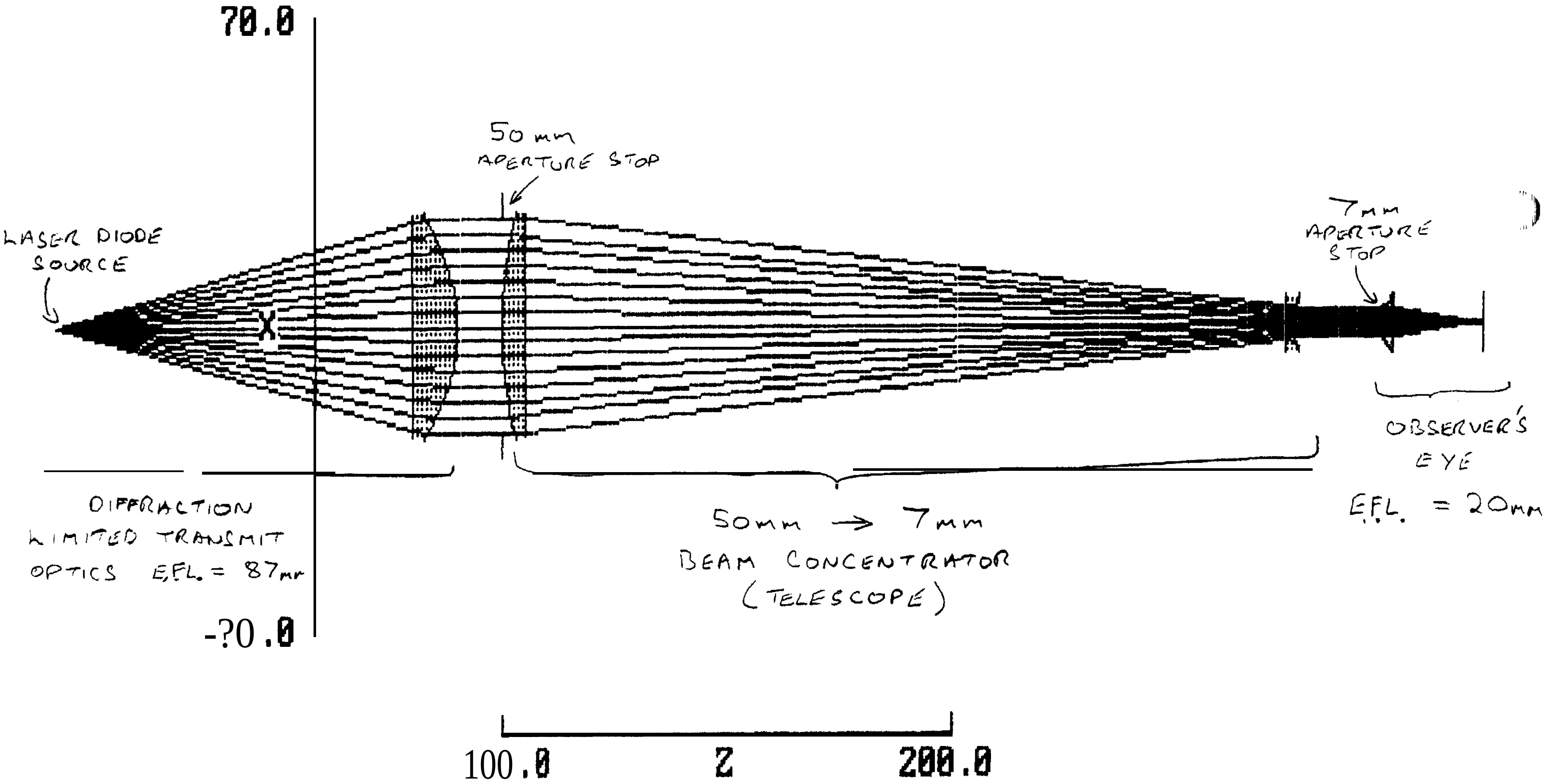
FIG. 1



The dependence o retinal lesion threshold on image size

FIG. 2

DIFFRACTION LIMITED OPTICAL SYSTEM



LAYOUT: Annotate ClrMenu Zaxis Hdim Vdim Posn Magn Random ElAz Quads ESC

FIG 3

IMAGE OF LASER DIODE LINE SOURCE AT THE OBSERVER'S EYE

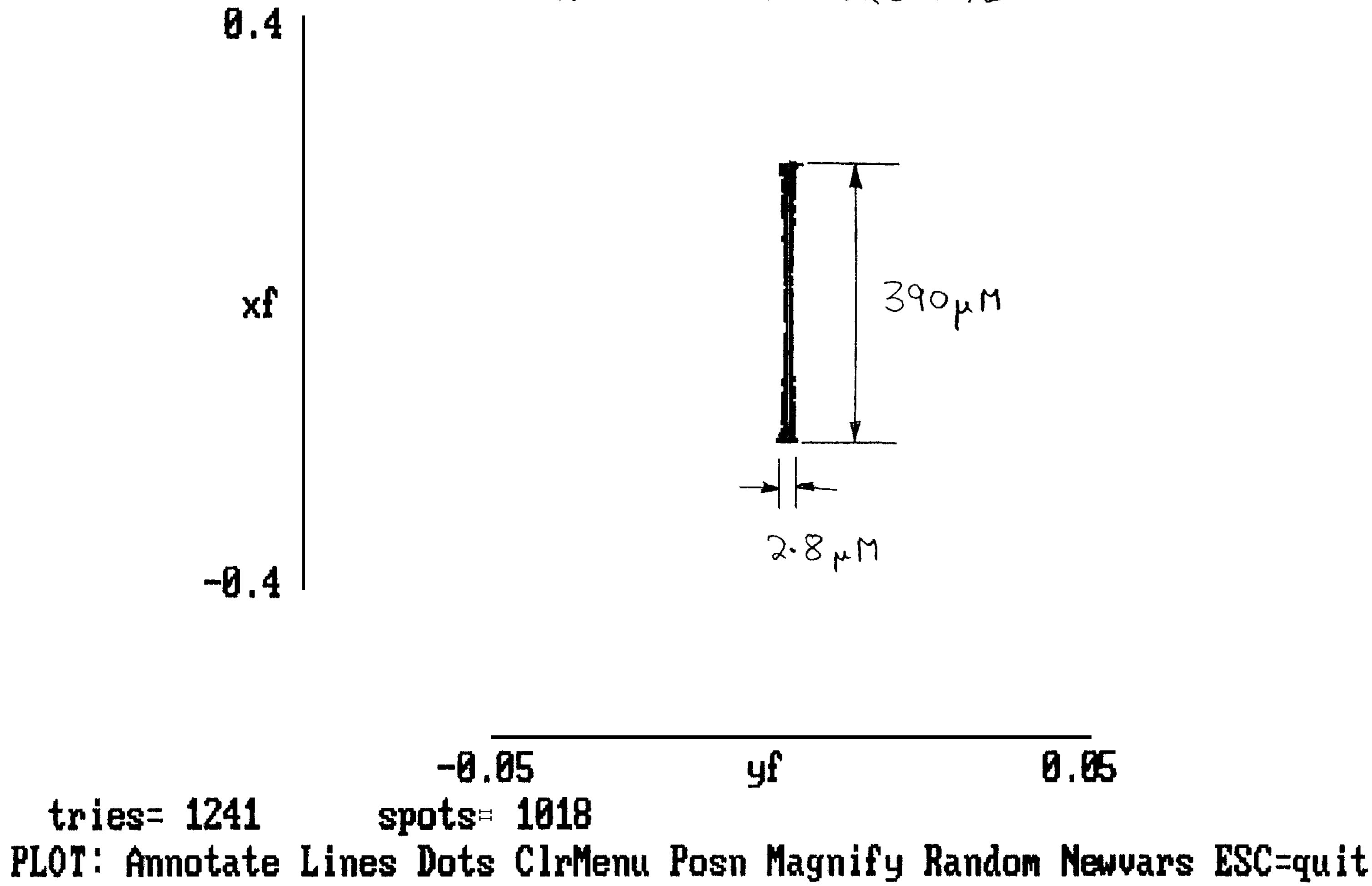
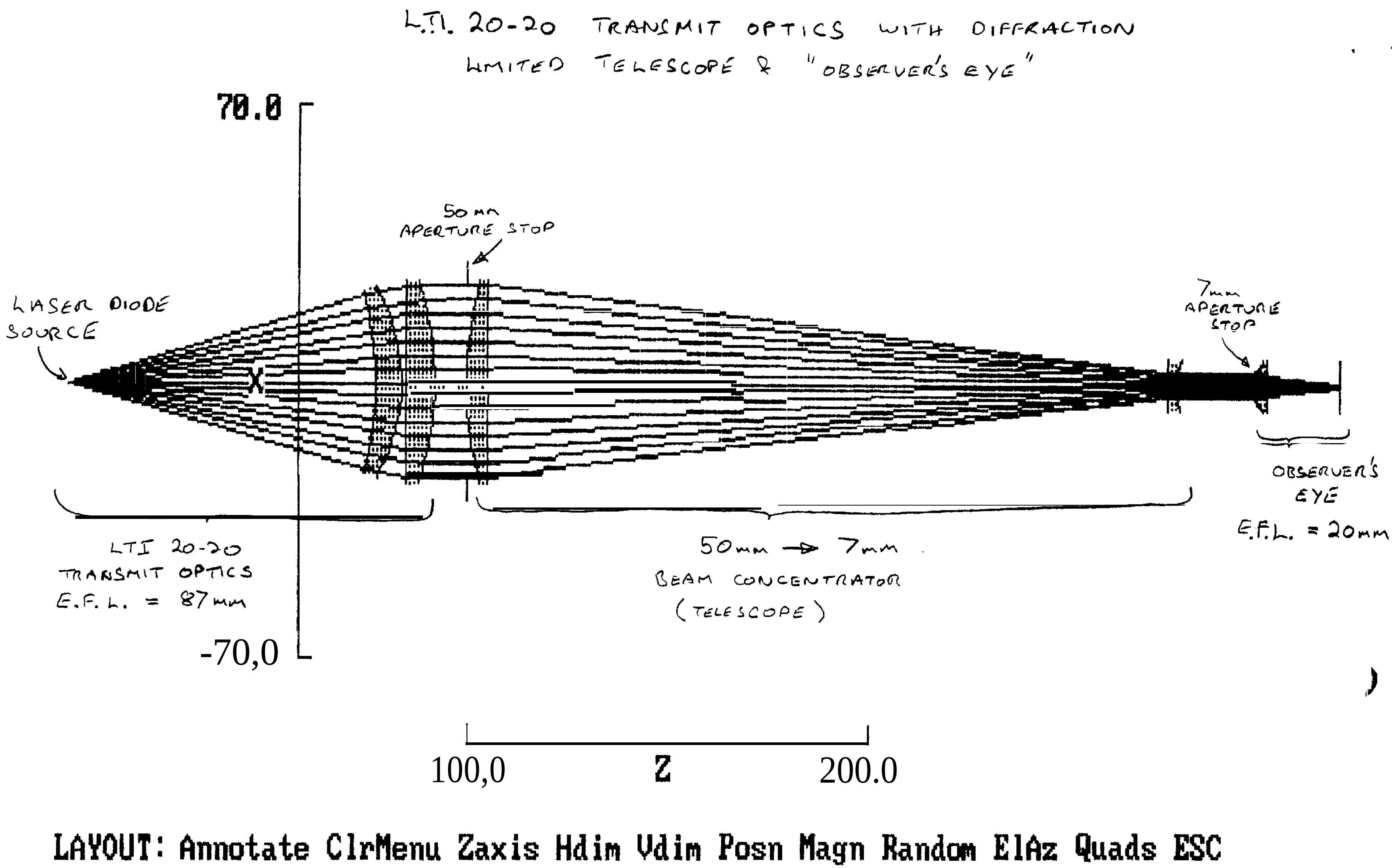


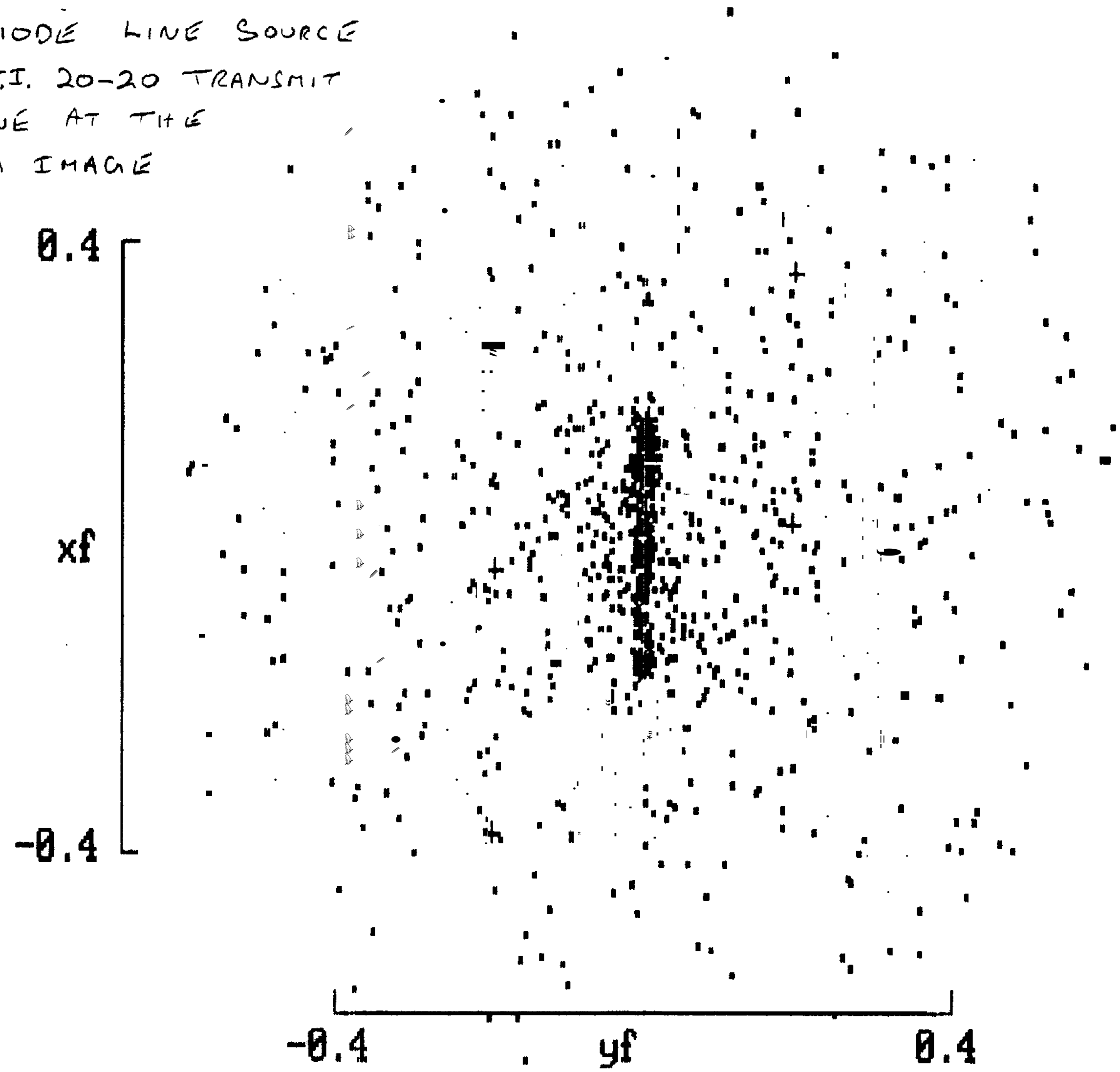
FIG. 4



L.T.I. 20-20 TRANSMIT OPTICS WITH DIFFRACTION LIMITED TELESCOPE & "OBSERVER'S EYE"
70.0
-70,0
LASER DIODE SOURCE
50 mm APERTURE STOP
7mm APERTURE STOP
OBSERVER'S EYE E.F.L. = 20mm
LTI 20-20 TRANSMIT OPTICS E.F.L. = 87mm
50mm → 7mm BEAM CONCENTRATOR (TELESCOPE)
100,0
Z
200.0
LAYOUT: Annotate ClrMenu Zaxis Hdim Vdim Posn Magn Random ElAz Quads ESC

FIG. 5

IMAGE OF LASER DIODE LINE SOURCE COLLIMATED BY L.T.I. 20-20 TRANSMIT OPTICS. FOCAL PLANE AT THE POSITION OF MAXIMUM IMAGE ENERGY DENSITY.

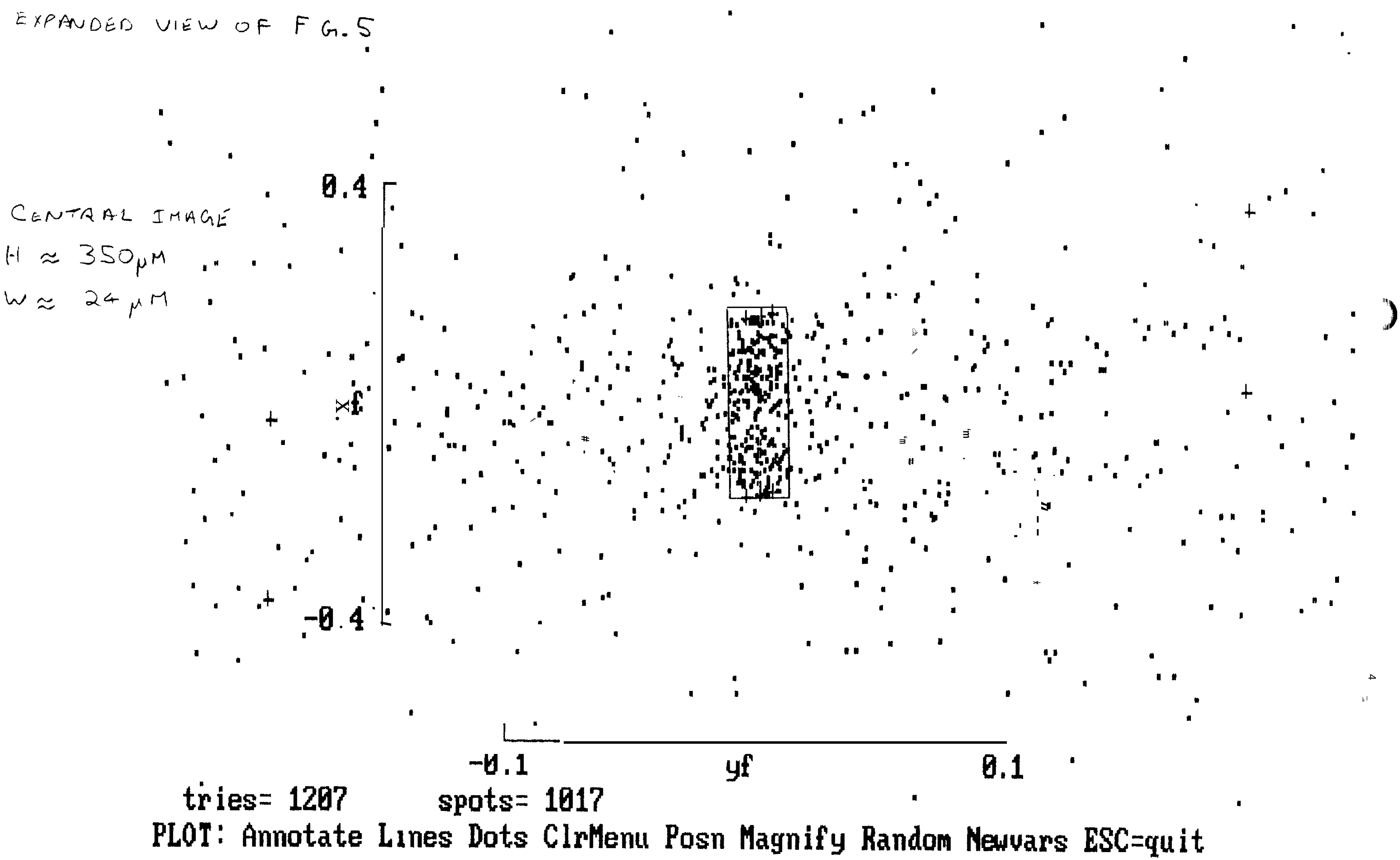


tries= 1226 spots= 1021

PLOT: Annotate Lines Dots ClrMenu Posn Magnify Random Newvars ESC=quit

FIG. 6

EXPANDED VIEW OF FG. 5



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Recipient Phone Number (Very Important) ( )

Company: Light Products Branch - FDA

Department/Floor No.

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13 FEDEX BOX
14 FEDEX TUBE

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56 FEDEX LETTER
52 FEDEX PAK*
53 FEDEX BOX
54 FEDEX TUBE

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3 ECONOMY

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41 GOV'T PACKAGE

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11
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